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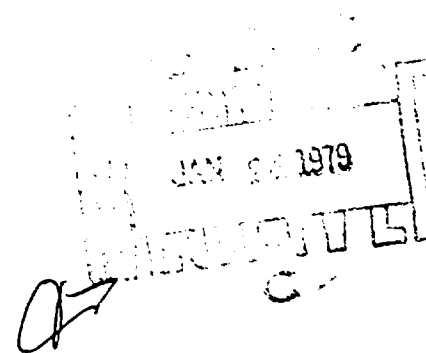
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DREO TECHNICAL NOTE NO. 78-14
DREO TN 78-14

PROFGEN: AN AIRCRAFT FLIGHT PROFILE GENERATION PROGRAM

by
Capt. M. Vinnins



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GENERATION PROGRAM

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Defence Electronics Division

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ABSTRACT

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RÉSUMÉ

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<u>TABLE OF CONTENTS</u>		<u>Page</u>
Abstract/Résumé		111
1.	BACKGROUND	1
2.	PROFGEN DEFINITION	1
3.	USE OF PROFGEN	3
	3.1 PRDATA Namelist	4
	3.2 PASDATA Namelist	5
	3.3 PROFGEN Outputs	6
4.	EXAMPLE PROFILE	9
APPENDIX A...PLOTS OF PROFGEN PARAMETERS		12

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PROFGEN

An Aircraft Flight Profile Generation Program

1. Background

The initial activity within the new DREO Technical Sub-Program on Navigation Technology has been devoted to research and development on strapdown inertial navigation systems (S/D INS). Included in this activity are system simulation, inertial component testing, and eventual design and testing of a complete strapdown INS. The application of such an INS would be both as an aid and a stand-alone backup to NAVSTAR Global Positioning System (GPS) User Equipment. The fact that NAVSTAR GPS is a radio navigation system makes the possibility of electronic jamming and interference a very real possibility in a military environment. An inertial navigation system is unaffected by jamming and thus can serve as an ideal backup system. Although strapdown sensor and system technology is a relatively new field, much promising work is being done by several American companies. Strapdown Technology eliminates the need for mechanically-levelled sensor platforms (gimbals) placing the burden, instead, upon computers. With recent developments in computer technology, small and efficient computers can be relied upon to carry out navigation functions on board any type of vehicle. Initial work in the navigation sub-program has involved study and simulation of a S/D INS for use in aircraft applications. Future work may involve maritime and land craft as applications arise.

The initial step in the development of the INS was the simulation of the various components of such a system. These include models of inertial sensors (gyroscopes and accelerometers); development of navigation algorithms, sensor error compensation and appropriate filtering techniques. For the purposes of the simulation, it was necessary to develop a method of driving the inertial sensors such that they appeared to be on board an aircraft. The outputs of the sensors could then be operated upon by the navigation algorithms, compensation and filters to obtain the desired 3-dimensional navigation solution.

The simulation of such an aircraft flight profile to drive the sensor models was accomplished using a computer program called PROFGEN (Profile Generation).

2. PROFGEN Definition

PROFGEN is a computer program which calculates flight path data for an aircraft moving over the earth. The program is in FORTRAN and was originally written by S.H. Musick of the Air Force Avionics Lab., WPAFB,

Dayton, Ohio¹.

PROFGEN, written in 1975, was intended to support simulations requiring a six degree-of-freedom trajectory to drive them. This program was made available to the navigation subgroup in July 1977 for use in the S/D INS simulation being developed at DREO. Several useful features of the program include wander-azimuth capability, user-determined output times, computation of attitude rates (as well as attitude) and an accurate gravity model. The program is coded in modular form making it very readable and easily modified.

PROFGEN Computes:

- 1) position in geographic latitude, longitude and altitude.
- 2) velocity; componentized and presented in a local-level (navigation) frame.
- 3) acceleration consisting of velocity rates of change summed with gravity.
- 4) attitude consisting of roll, pitch and yaw, and
- 5) attitude rate for roll, pitch and yaw.

For the purposes of the S/D INS Simulation, the angular rates and accelerations have been modified by the DREO navigation group such that they are presented in the vehicle body frame with respect to the inertial frame (earth rotation and gravity considered). Roll, pitch and yaw are considered to be the angles between the body and navigation frame axes.

PROFGEN models a point mass responding to 4 possible flight manoeuvres specified by the user:

- 1) vertical turns (pitch up or down)
- 2) horizontal turns (with a coordinated roll)
- 3) sinusoidal heading changes, and
- 4) straight flight (great circle or rhumb line)

A coordinated turn in horizontal-plane manoeuvres means that the aircraft is rolled to an angle where the vector sum of the centrifugal turning force and the force of gravity act perpendicular to the wings.

1. PROFGEN-A computer program for generating flight profiles S.H. Musick, Nov. 76, WPAFB, AFAL-TR-76-247.

The user of the program may select either rhumb line or great circle flight path. In rhumb line flight the aircraft maintains constant heading angle during straight flight, whereas, in a great circle path the aircraft flies in a fixed plane during straight flight maintaining this fixed plane, even when altitude changes, by correcting heading continuously. When not in straight flight the rhumb line or great circle is superimposed on the manoeuvre.

The earth is modelled within the program as an ellipsoid having values for eccentricity, semimajor axis length, spin velocity and gravitational constant as defined by the World Geodetic System 1972.

Earth's gravity is modelled as a function of latitude and altitude, having both radial and level components. This model is accurate to approximately 25 μ g's.

The outputs of PROFGEN, instantaneous acceleration, velocity and position, are provided by a 5th order Kutta-Merson numerical integrator which also allows variable step-size integrations, as determined by the user, to control the rate and growth of errors.

There are several limitations to PROFGEN and, therefore, before describing the use of the program these should be briefly discussed:

- 1) Since the program models a point mass, the path coordinate frame and body coordinate frame are coincident. This means that it is not possible to simulate a slipping or crabbing motion for the aircraft.
- 2) There is no noise model within the program meaning that aircraft vibrations and noise cannot be simulated without additions to PROFGEN.
- 3) The program is very slow if the output interval desired is very short (50 outputs per second or more). This is due to the fact that the integrator must adjust its step size very finely in order to satisfy the desired output time and allowed error limitations chosen by the user. This limitation can be reduced if data is recorded from PROFGEN and later used without running the whole program again.

PROFGEN is approximately 2500 FORTRAN-coded lines long and occupies approximately 16k of core memory. The program is used on a SIGMA IX computer on the DREO site and output data is recorded on disk for later use in driving the sensor models of the S/D INS simulation.

3. Use of PROFGEN

The operation of PROFGEN is controlled by two input data namelists supplied by the user. These are PRDATA, initial problem data and PASDATA, specific data for each segment.

PROFGEN is structured such that only one of the four possible manoeuvres can be executed at a time but it can commence from any aircraft attitude. A flight profile is created by stringing together a sequence of manoeuvres, called flight segments, and specifying how long each will last. The final values of position, velocity, acceleration and attitude for each segment are used as initial values for the next segment giving uninterrupted time histories for all variables.

The user can also control aircraft acceleration within each segment, superimposing it over any manoeuvre. An additional feature of PROFGEN is the incorporation of the flight envelope for the Convair 580 aircraft into the program². If roll, pitch, yaw or velocity are out of range of the vehicle's capabilities, a message is printed out to the user. It should be noted, though, that this does not stop or affect the running of PROFGEN; it only provides information to the user.

In general, then, a very realistic flight profile can be generated by the user simply by specifying initial program and flight segment parameters in the two namelists. These namelists will now be discussed in more detail.

3.1 PRDATA namelist

The PRDATA namelist specifies the initial conditions of the program and the initial aircraft parameters with which the flight profile will begin. These initial values are (as coded within the program):

- NSEGT - the number of segments in the entire flight profile.
- TSTART - the start time (usually time zero).
- VTO - initial velocity in feet per second.
- PHEADO - initial heading of path coordinate frame in degrees.
- PITCHO - initial pitch from level flight in degrees.
- ALFAO - heading from north in the navigation frame in degrees.
- LATO - initial latitude.
- LONO - initial longitude.
- ALTO - initial altitude.
- IPRNT - print out control; if set, then a formatted data printout is provided as PROFGEN runs.

2. The National Aeronautical Establishment Convair 580 is the aircraft on which DREO plans to flight test the developed S/D INS.

- ROLRAT - rollrate, maximum allowed in degrees per second.
- IDSWSCH - enables data to be written on disk if set.

Several other plot and data storage variables exist enabling various output data options. These are dependent upon the users' needs and are not ordinarily employed. The parameters in the PRDATA namelist set all of the initial conditions required before running the program. When these parameters are initialized, the next namelist, PASDATA, is read.

3.2 PASDATA namelist

The PASDATA namelist contains the problem specifics for each segment within the flight profile. As stated above, the PRDATA parameter NSECT is the number of segments in the flight profile. Within the PASDATA namelist each parameter will have values for every segment (i.e. if there are 20 segments then each PASDATA parameter will have 20 values, one for each segment).

The PASDATA namelist contains the following parameters:

- SEGLNT - the segment length in seconds.
- TURN - type of manoeuvre (any one of the 4 possible manoeuvres)
- PACC - acceleration along the velocity vector (path acceleration) in g's.
- TACC - maximum centrifugal acceleration in a vertical or horizontal turn (turn acceleration in g's.
- HEAD - heading change desired within that segment (for turns only) in degrees.
- DTO - desired output interval in seconds for disk storage.
- NPRNT - desired printout interval (can be different from DTO).
- ERROR - maximum error allowed in the integrator.
- HMAX - maximum step size allowed in the integrator.
- HMIN - minimum step size allowed in the integrator.
- PITCH - desired pitch in degrees (vertical turns only).
- MODE - fixed or variable step size integration option.
- NPATH - nominal path, either rhumb line or great circle.

As many as 50 segments are allowed for an entire flight profile and each segment may last as long as desired by the user. An example of a PRDATA and a PASDATA namelist are shown in Figures 1 and 2 respectively.

A printout of PROFGEN's output data can be obtained by selecting a printout option in the PASDATA namelist. The printout is formatted such that a "header" is printed at the beginning of each flight segment. This header describes the segment and what happens in it; the type of manoeuvre, start and end times, time to achieve heading or pitch changes etc.

3.3 PROFGEN Outputs

The outputs provided by PROFGEN are:

TIME	-	in seconds
LAT	-	latitude
LON	-	longitude
ALPHA	-	heading of navigation frame from north in degrees
ALT	-	altitude in feet
ROLL	-	in degrees
PITCH	-	in degrees
YAW	-	in degrees
PSI	-	in degrees
DROLL	-	derivative of roll (deg/sec)
DPITCH	-	derivative of pitch (deg/sec)
DYAW	-	derivative of yaw (deg/sec)
VX	-	velocity along X axis (ft/sec) (navigation coordinate frame)
VY	-	velocity along Y axis (ft/sec) (navigation coordinate frame)
VZ	-	velocity along Z axis (ft/sec) (navigation coordinate frame)

```
E PRDISK
EDIT HERE
XTY 1-20      &PRDATA IPRB=1,
1.000 NSEGT=2,
2.000 IDSKSUCH=1
3.500 LLMECH=2,
3.000 TSTART=0.0,
4.000 PASPR=1,
4.500 VTO=0.0,
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6.000 PITCH0=0.0,
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8.000 LAT0=45.0,
9.000 LON0=-60.0,
10.000 ALTO=0.0,
11.000 IPRNT=1,
12.000 IRITE=0,
13.000 IPLOT=0,
14.000 ROLRAT=20.0,&END
15.000
--EOF HIT AFTER 15.
*
```

Fig. 1 PRDATA Namelist

[illegible]

Fig. 2 PASDATA Namelist

VPATH - path velocity (ft/sec)
FX - force in X (ft/sec/sec)
FY - force in Y (ft/sec/sec)
FZ - force in Z (ft/sec/sec)
APATH - path acceleration (ft/sec/sec)

The format of this output can be seen on the printout, Fig. 3, along with the previously-mentioned "header" information.

4. Example Profile

As mentioned earlier, PROFGEN is used to provide the data to drive models of inertial sensors in a manner simulating that of an aircraft in motion. The test profile which has been chosen for this work is a "racetrack-shaped" profile consisting of a takeoff, vertical climb to approximately 7,000 feet, levelling out, 4 horizontal turns to the left separated by several minutes of level flight and, finally, a descent to landing. A sketch of this profile showing the length of each segment is shown in Fig. 4. The entire flight is 1750 sec (29 min. 10 secs.) long.

In order to illustrate the dynamics of PROFGEN's flight profile, plots of the various output parameters with respect to time have been included as Appendix A to this report. A close study of the plots will show that all of the variables have uninterrupted time histories over the entire flight profile. PROFGEN, as described here, is at present in use in on-going navigation system simulation.

More detailed documentation and mathematical formulations of PROFGEN are available along with sample runs for various profiles. Further information may be obtained from the Electromagnetics Section, DREO/DED.

BEGIN SEGMENT NUMBER 2 30.00000
 INITIAL TIME 150.00000
 FINAL TIME 150.00000
 THIS FLIGHT SEGMENT IS A VERTICAL TURN
 THE NORMAL FLIGHT PATH OVER THE EARTH IS A BILBO LINE
 THE INTEGRATION STEP SIZE IS VARIABLE
 THE LOCAL-LEVEL RECONIZATION IS CONSTANT ALPHA
 THE DESIRED CHANGE-IN-PITCH IS ACHIEVED AT TIME 30.14905517
 30.00000 .0000000
 .1377430E-17 -.585030E-04
 -.1616155E-01 -32.15644

ESBIRCONFT SPEED IS OUTSIDE THE RANGE 50 TO 300 KNOTS. TOO FAST FOR COMRAIR!

TIME	30.00000	LCN	-59.93149534	ALPHA	-90.00000000	ALT	.000000000
LAT	45.00000000	PITCH	.032000000	YAU	.000000000	PSI	90.00000000
ROLL	.000000000	DPITCH	.000000000	DYAU	.000000000	UPATH	146.6577800
DROLL	.000000000	UV	-.2755064781E-28	VZ	.000000000	APATH	.000000000
UX	146.6577800	FV	-.1615154589E-01	FZ	-32.15643776		
FX	.3033069355E-42	AT ELAPSED CPU TIME	4.232 SEC.				
SECTIMER CALLS	0						
40.00000	.0000000		.0000300				
.182004E-04	-.587306E-04		6.767241				
-.165046E-01	-.578472E-04						

ESBIRCONFT SPEED IS GREATER THAN 10 OR LESS THAN -20 DEGREES.
 COMRAIR CANT DO THAT!!

TIME	40.00000	LCN	-59.98582664	ALPHA	-90.00000000	ALT	356.7612316
LAT	45.00000000	PITCH	10.42000007	YAU	.000000000	PSI	90.00000000
ROLL	.000000000	DPITCH	.000000000	DYAU	.000000000	UPATH	152.7500022
DROLL	.000000000	UV	-.2755064781E-28	VZ	26.52475978	APATH	1.100666667
UX	150.4293664	FV	-.1655064781E-01	FZ	-31.66618765		
FX	6.767240E-1	AT ELAPSED CPU TIME	11.840 SEC.				
SECTIMER CALLS	2						
50.00000	.0000000		.0000000				
.1033721E-04	-.5952061E-04		7.733092				
-.1854694E-01	-.586252E-04						

ESBIRCONFT SPEED IS GREATER THAN 10 OR LESS THAN -20 DEGREES.
 COMRAIR CANT DO THAT!!

TIME	50.00000	LCN	-59.97072314	ALPHA	-90.00000000	ALT	534.8129138
LAT	45.00000000	PITCH	10.40000000	YAU	.000000000	PSI	90.00000000
ROLL	.000000000	DPITCH	.000000000	DYAU	.000000000	UPATH	169.5655578
DROLL	.000000000	UV	-.2755064781E-28	VZ	29.44475000	APATH	2.146666667
UX	166.9894759	FV	-.1854694444E-01	FZ	-31.66335282		
FX	7.733091665	AT ELAPSED CPU TIME	13.300 SEC.				
SECTIMER CALLS	2						

Fig. 3 PROFGEN Printout Format

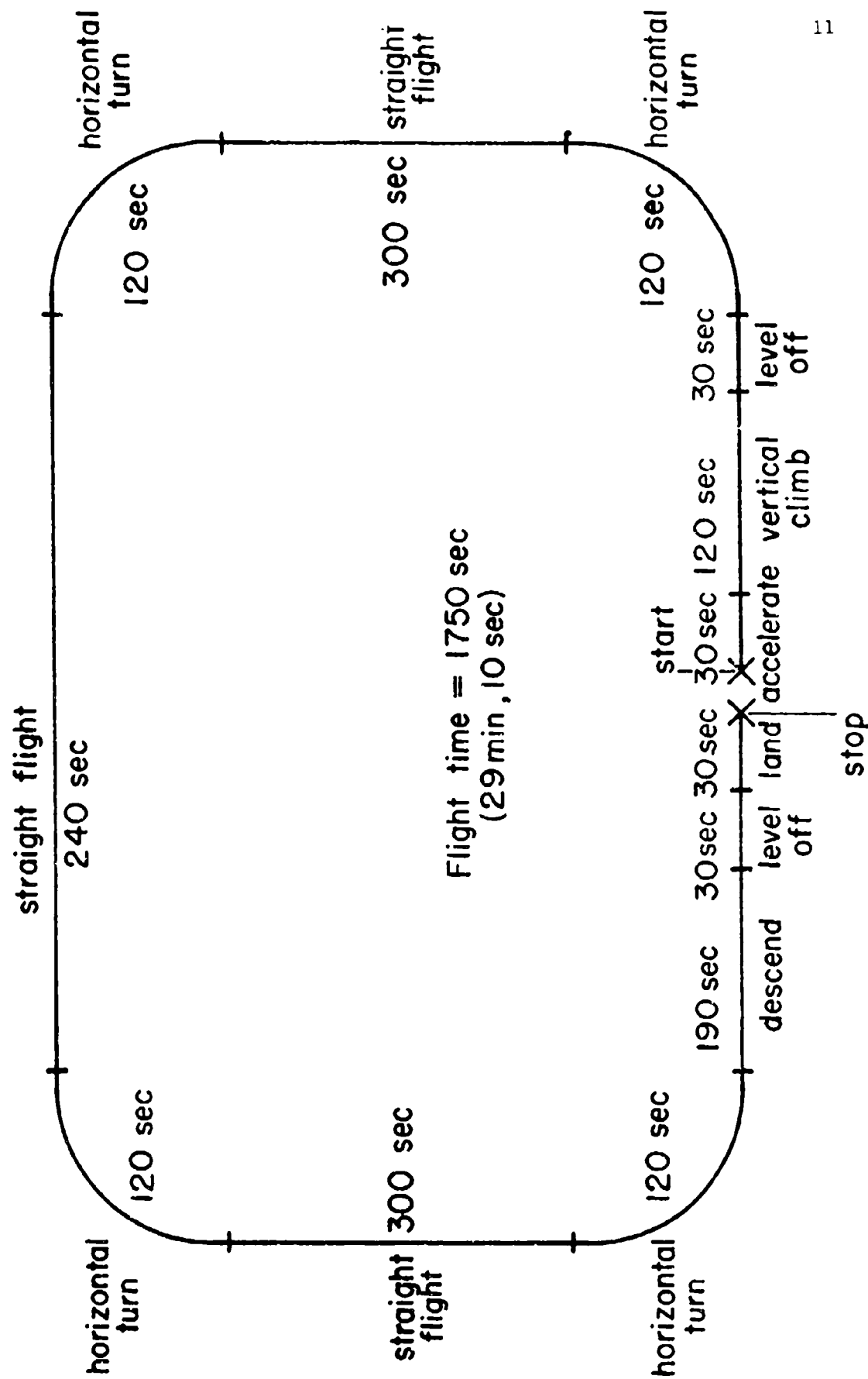
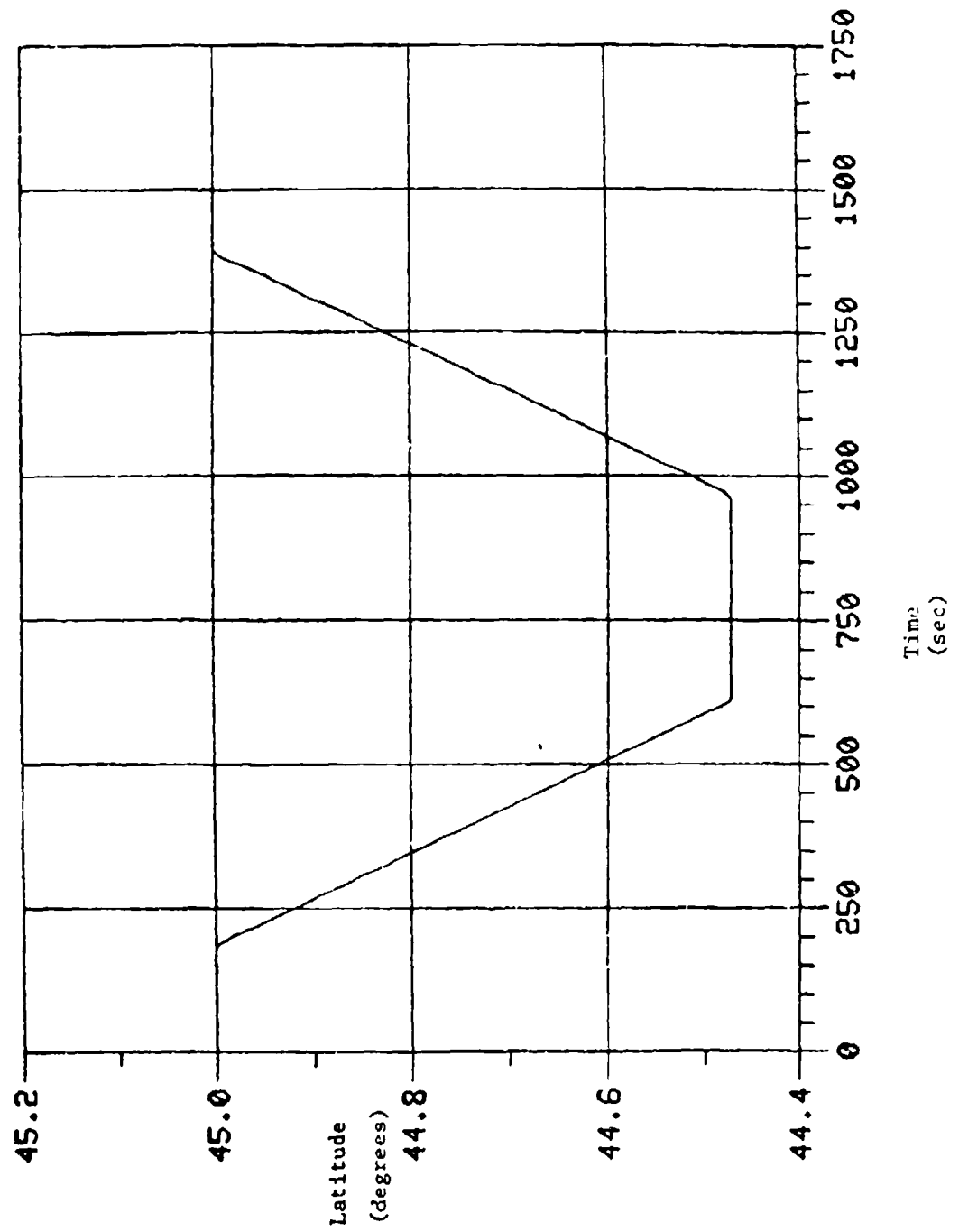
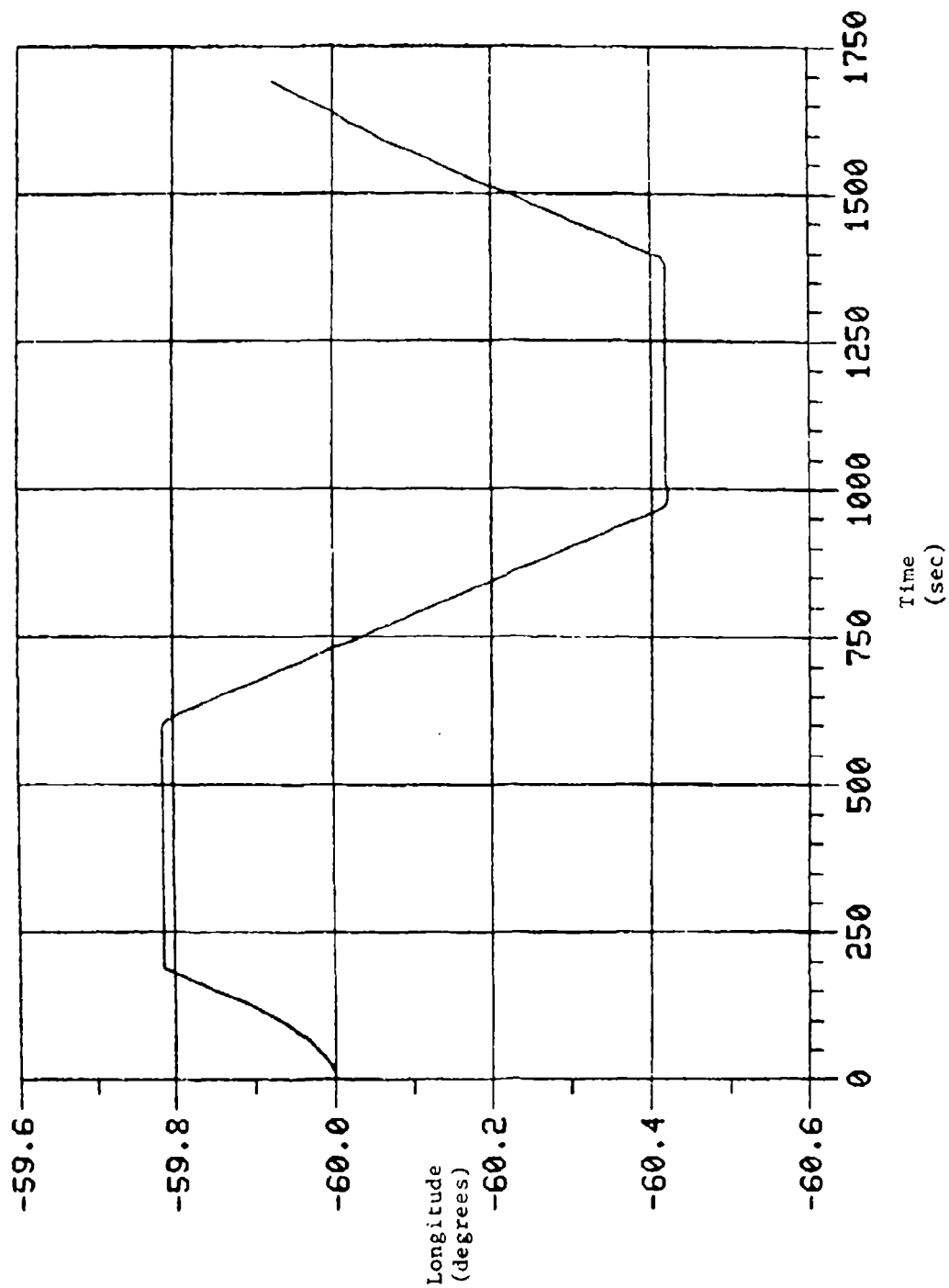


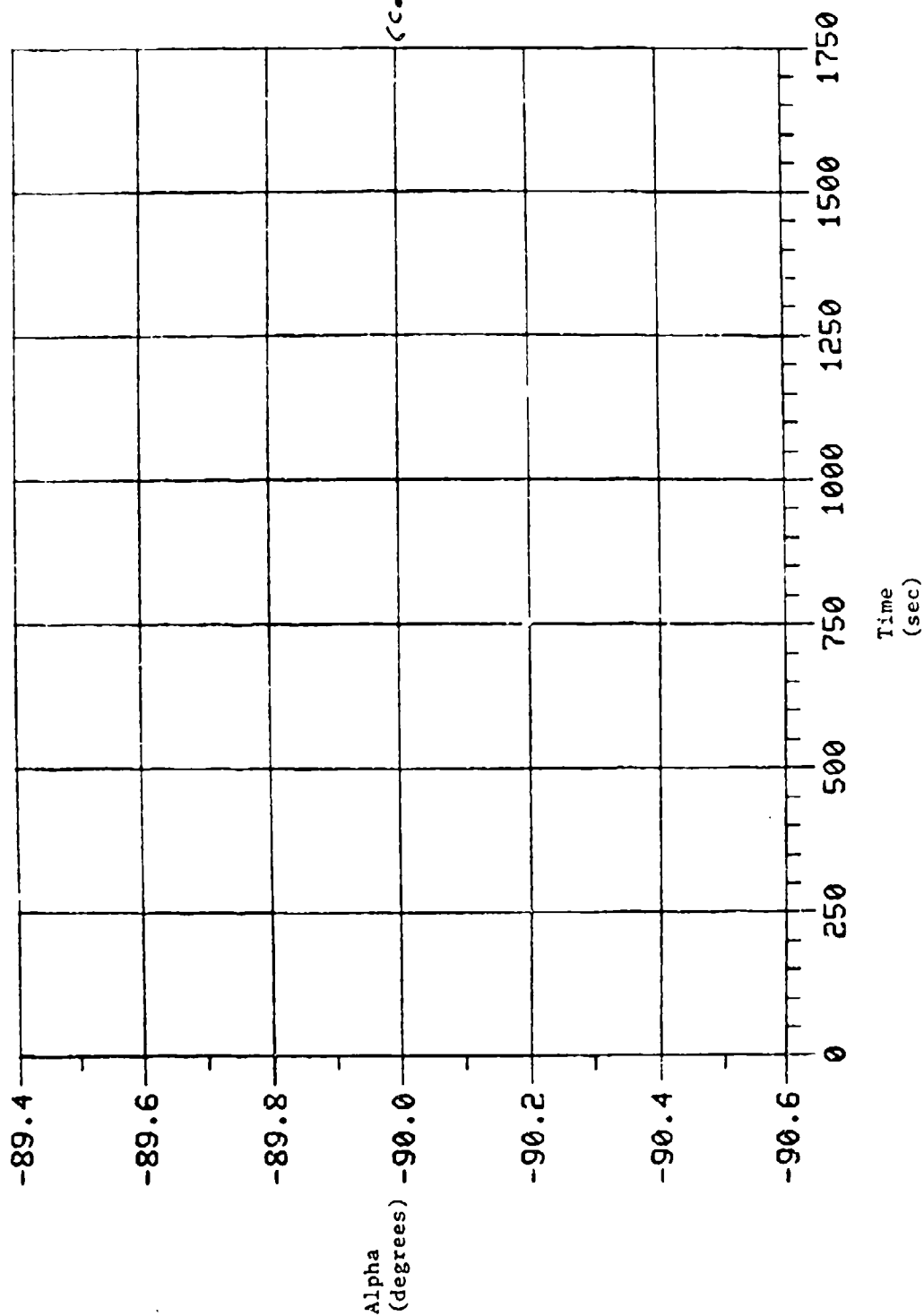
Fig. 4. 'Racetrack' Flight Profile

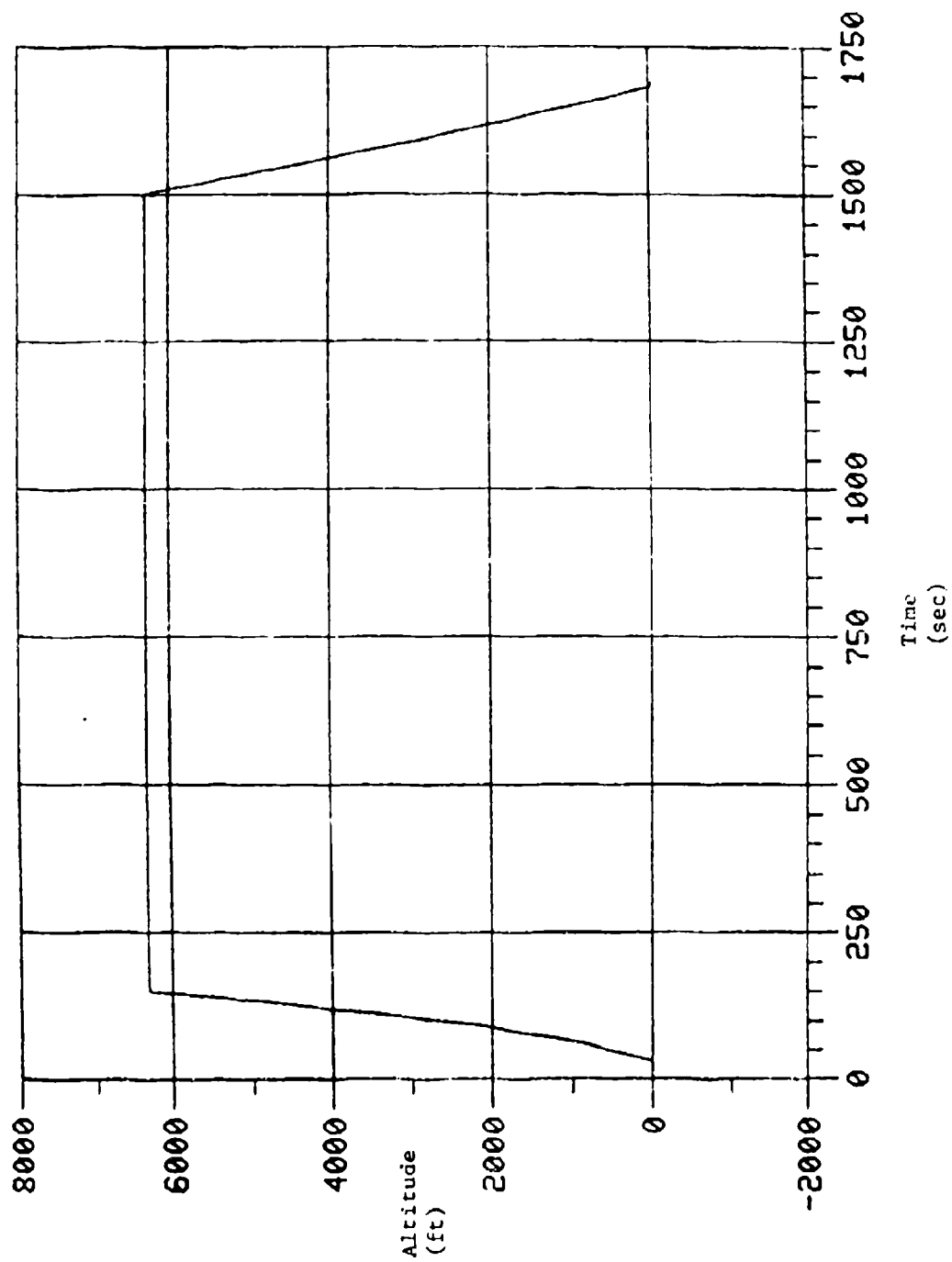
APPENDIX A

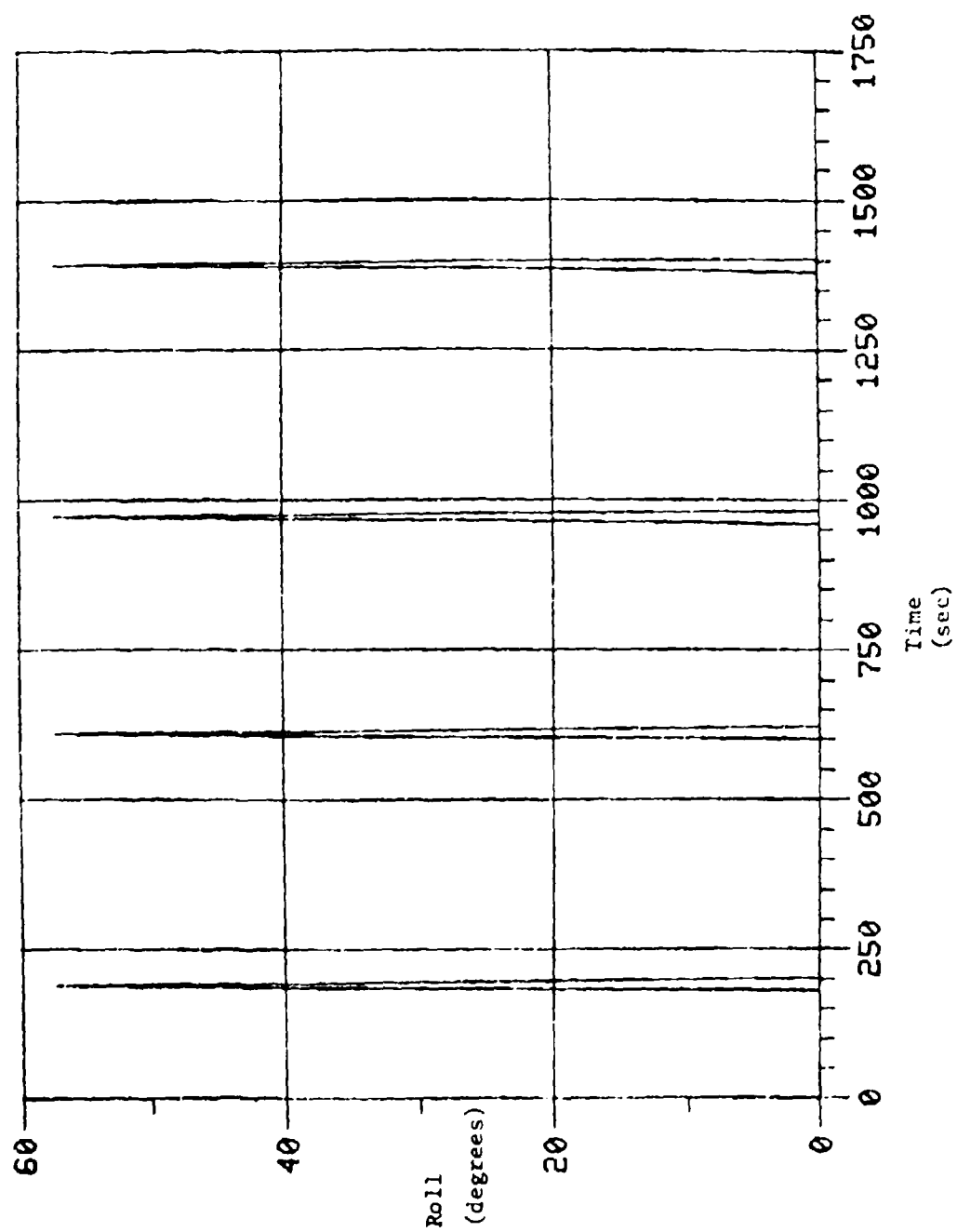
Plots of PROFGEN Parameters

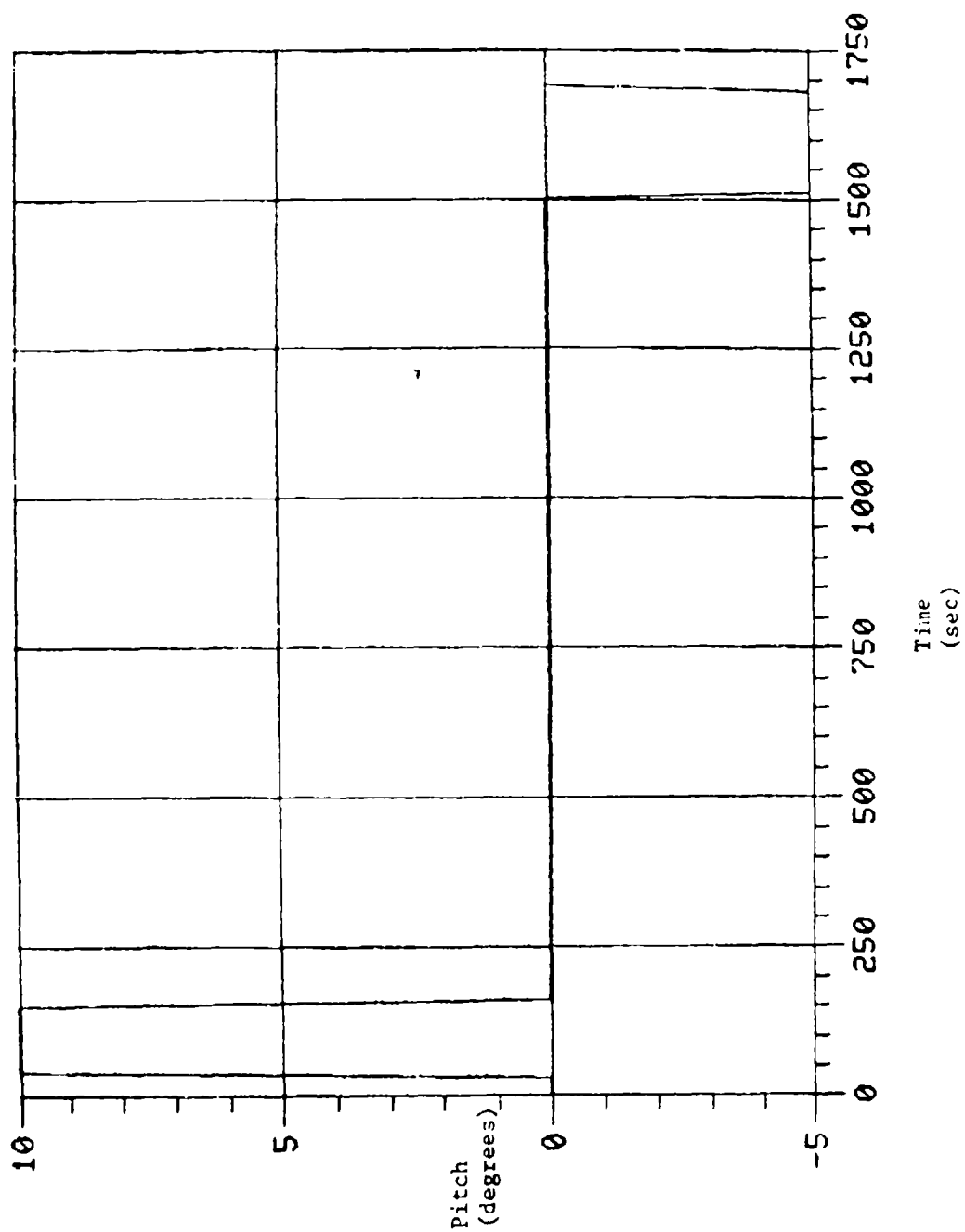


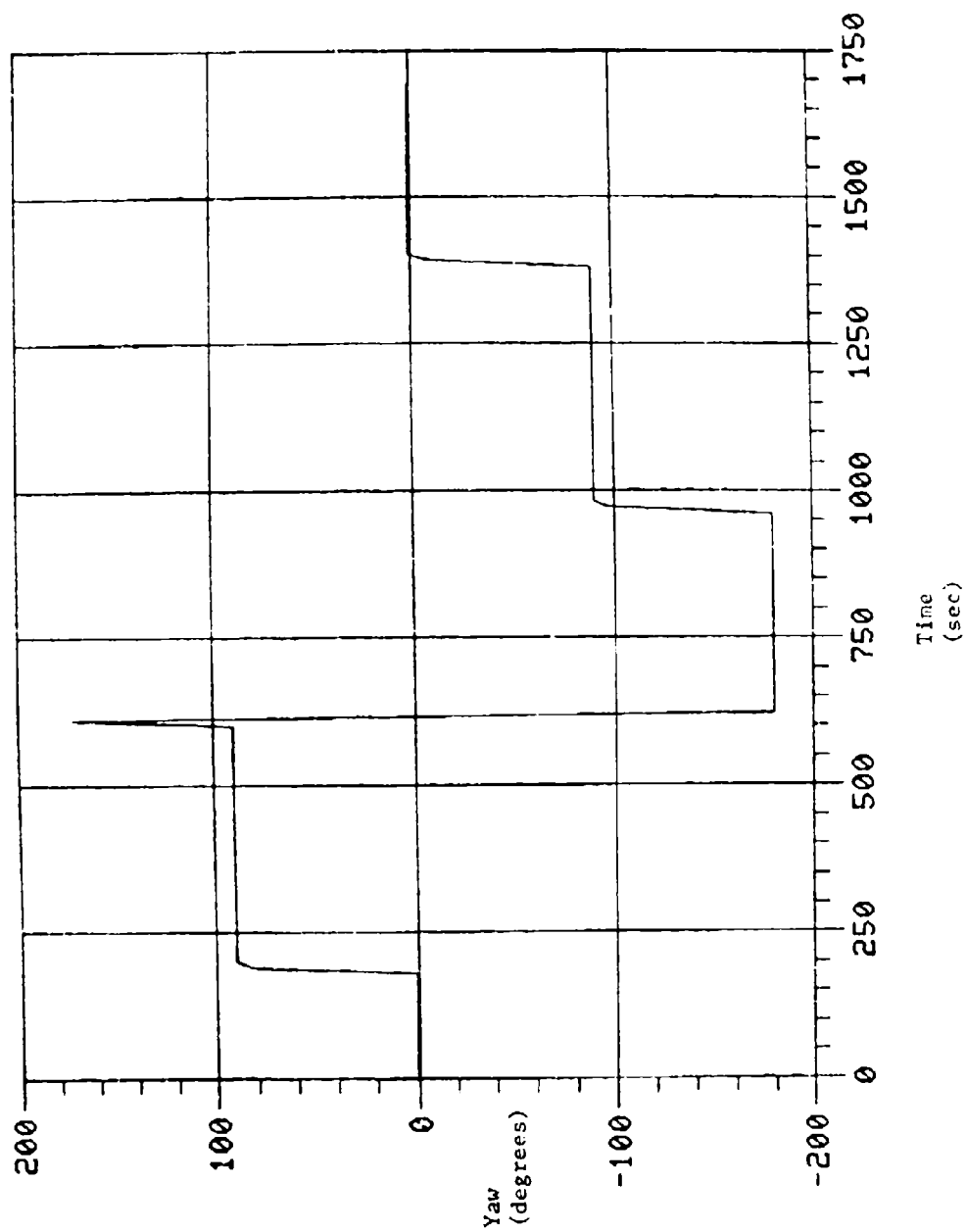


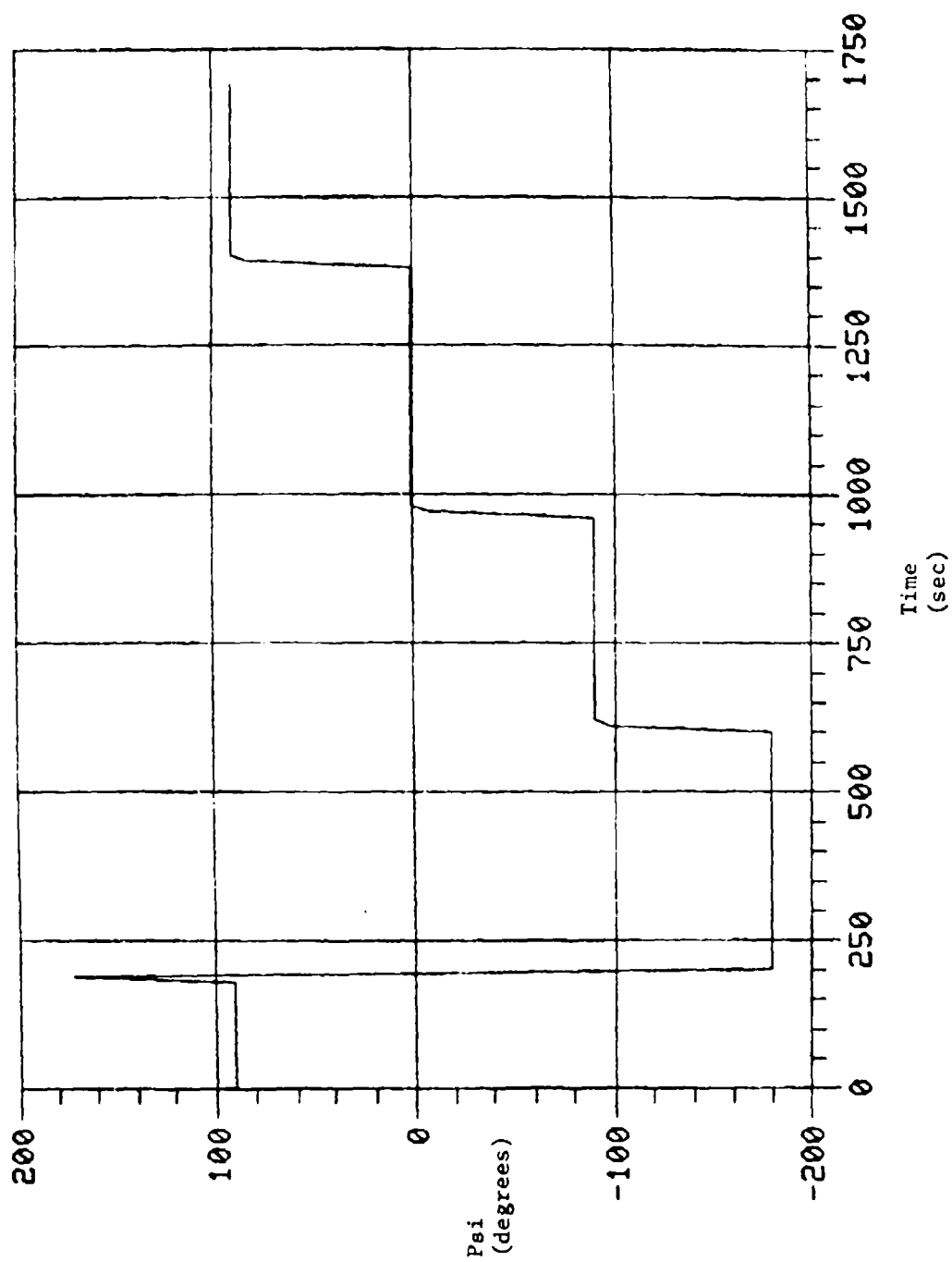


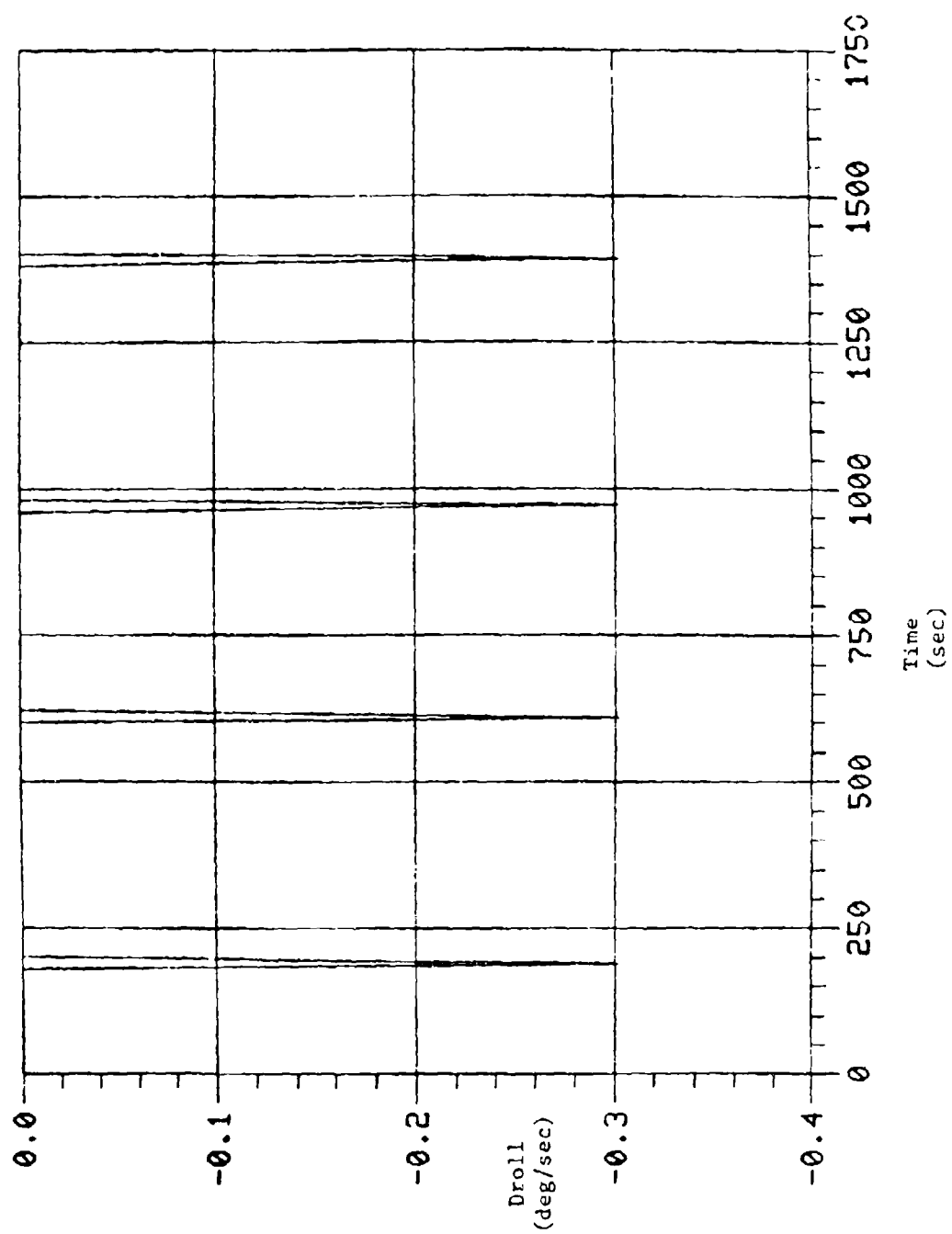


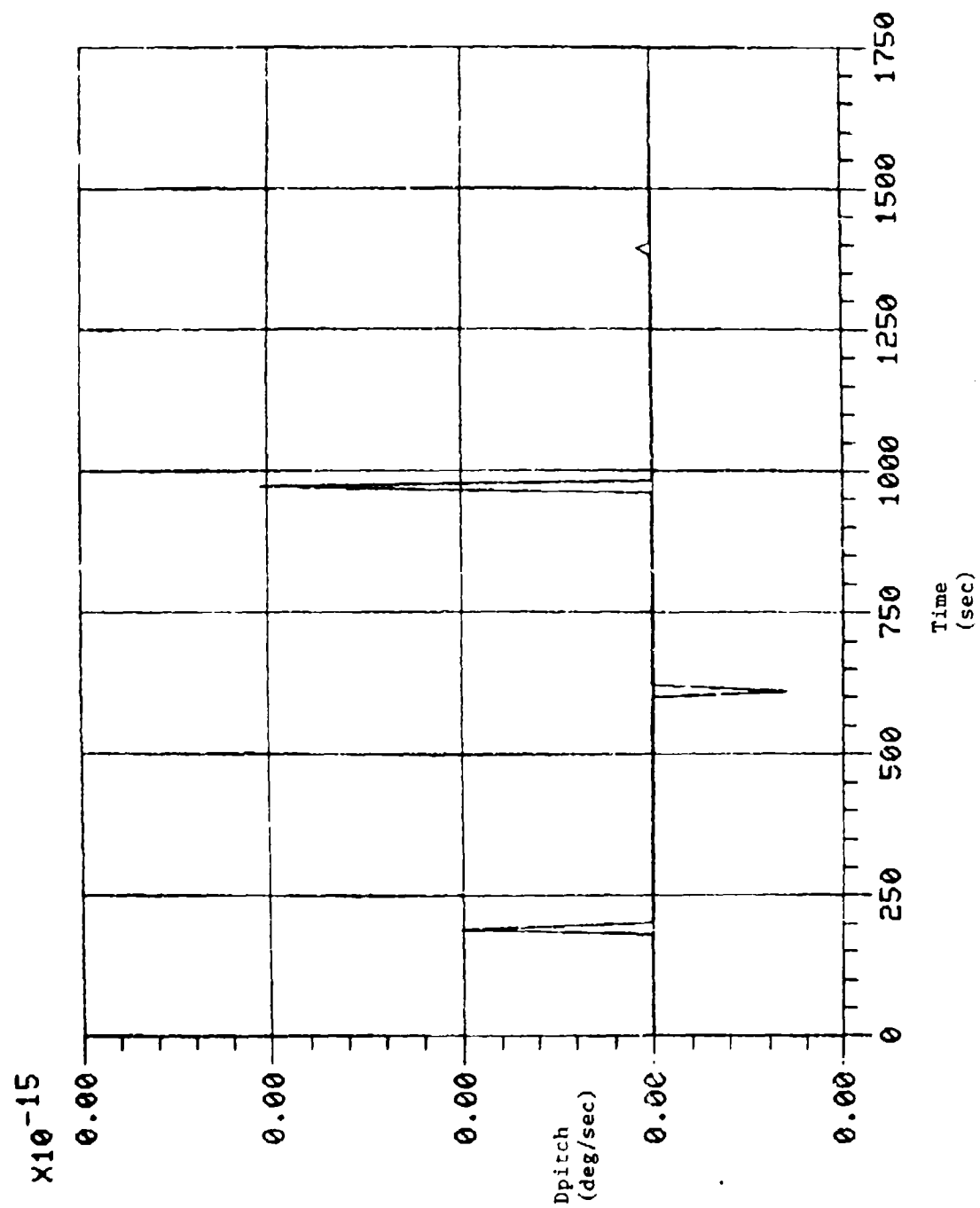


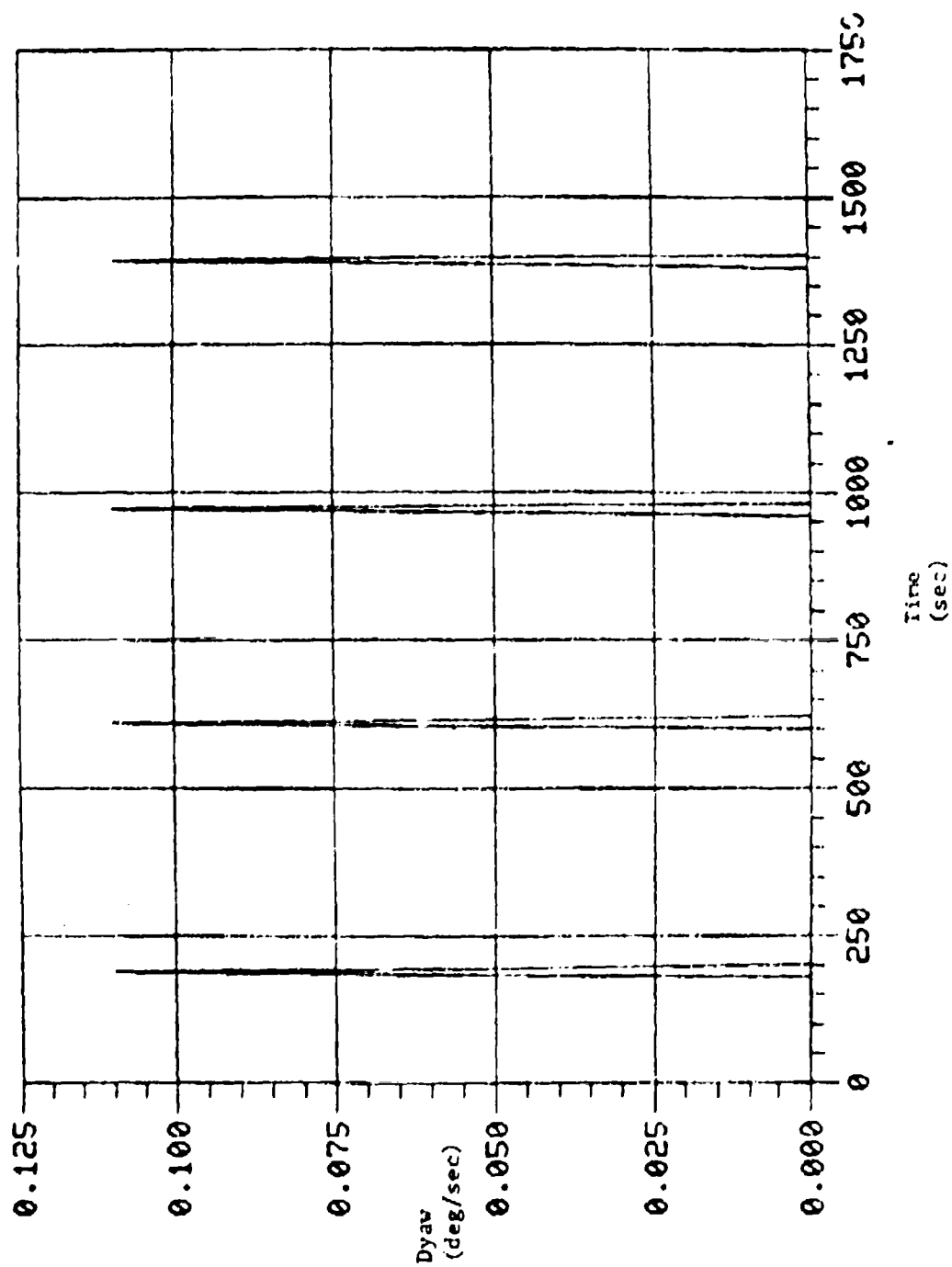


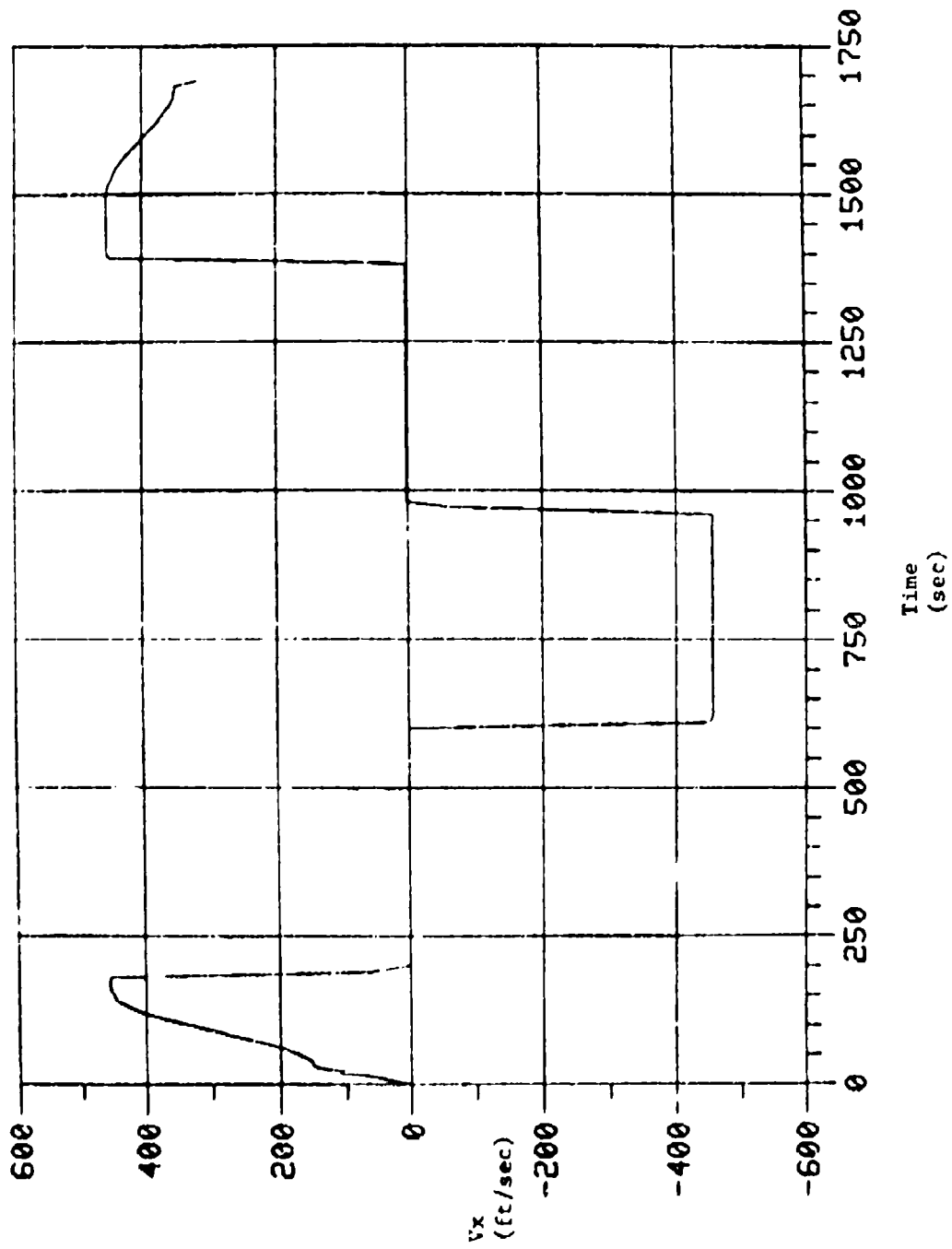


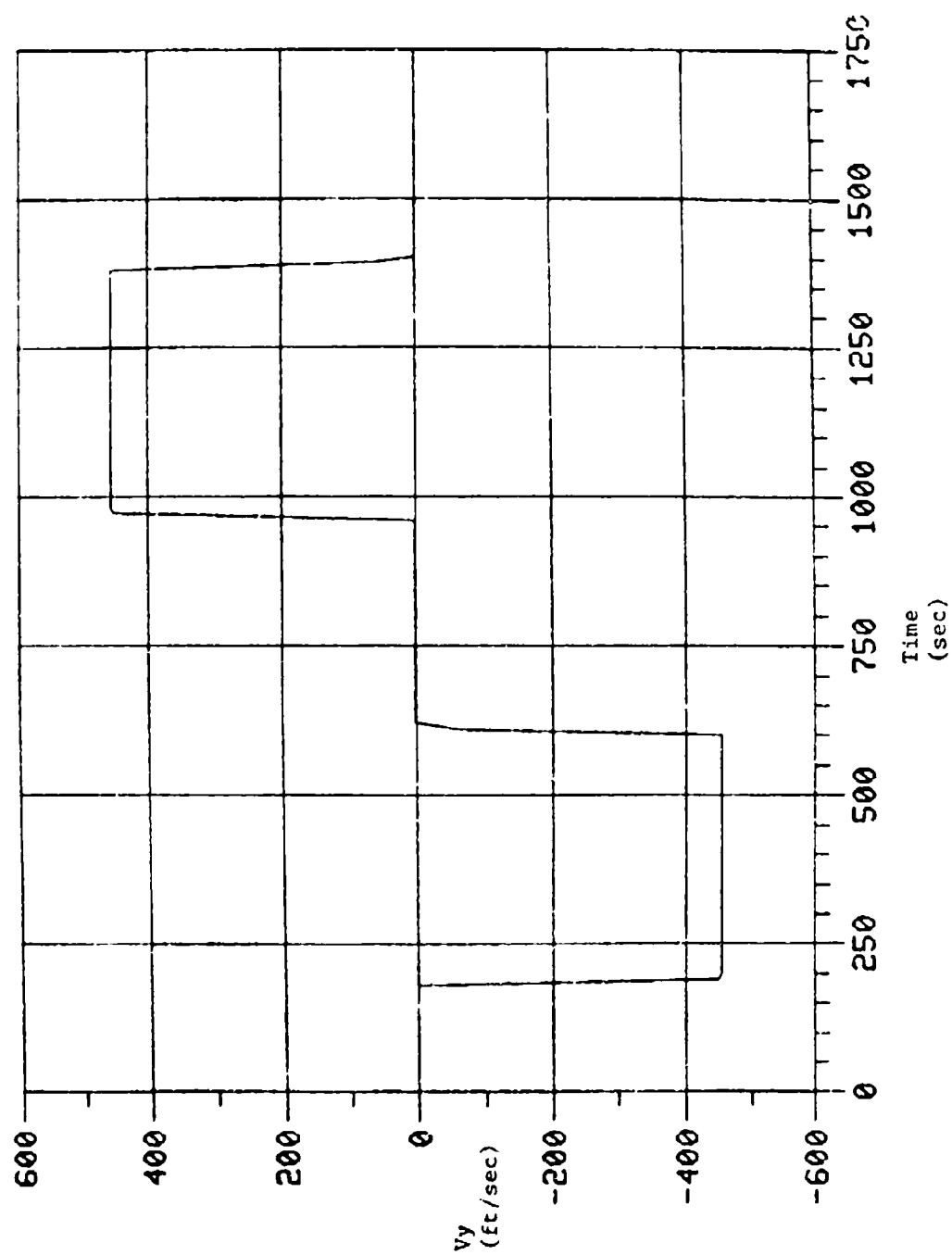


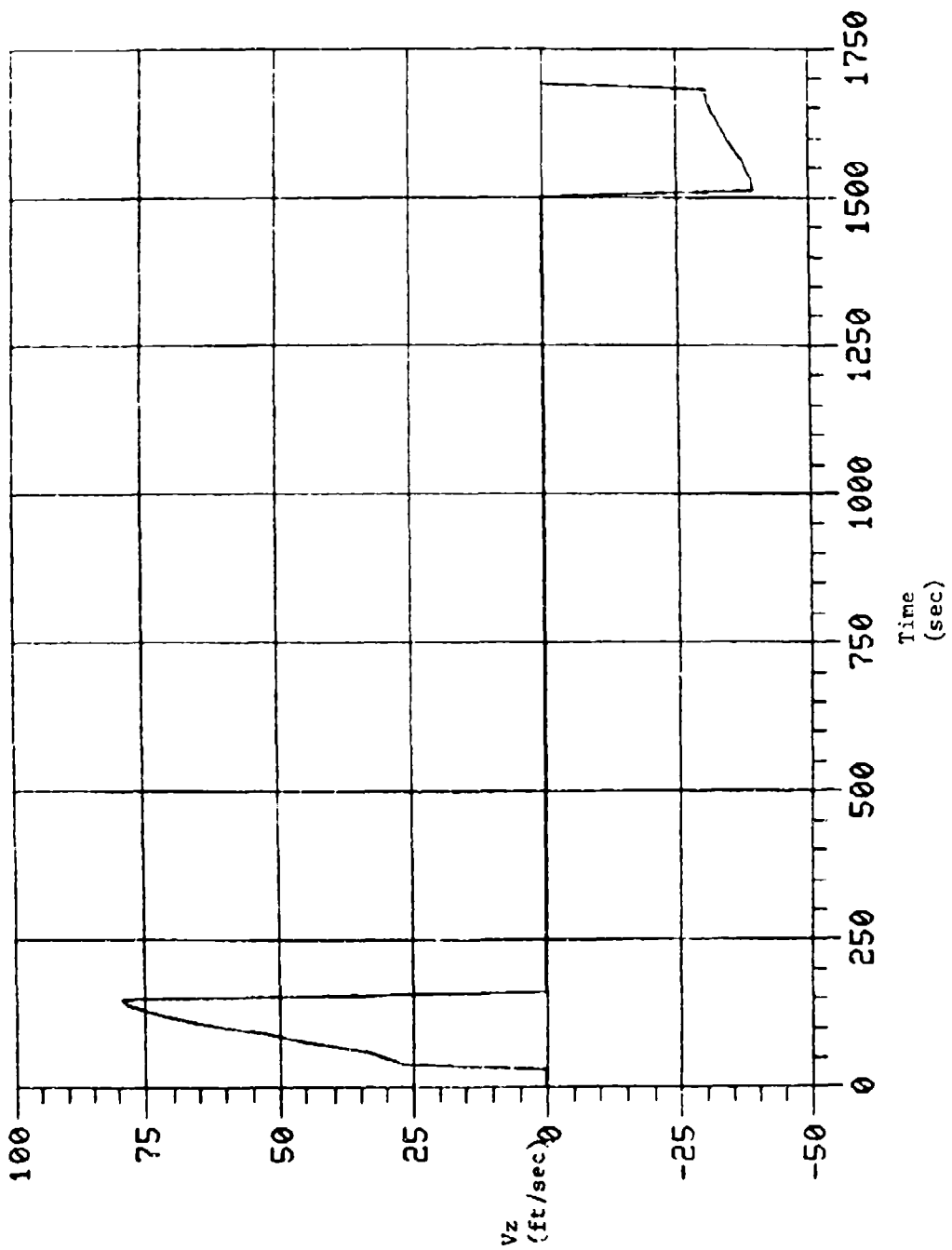


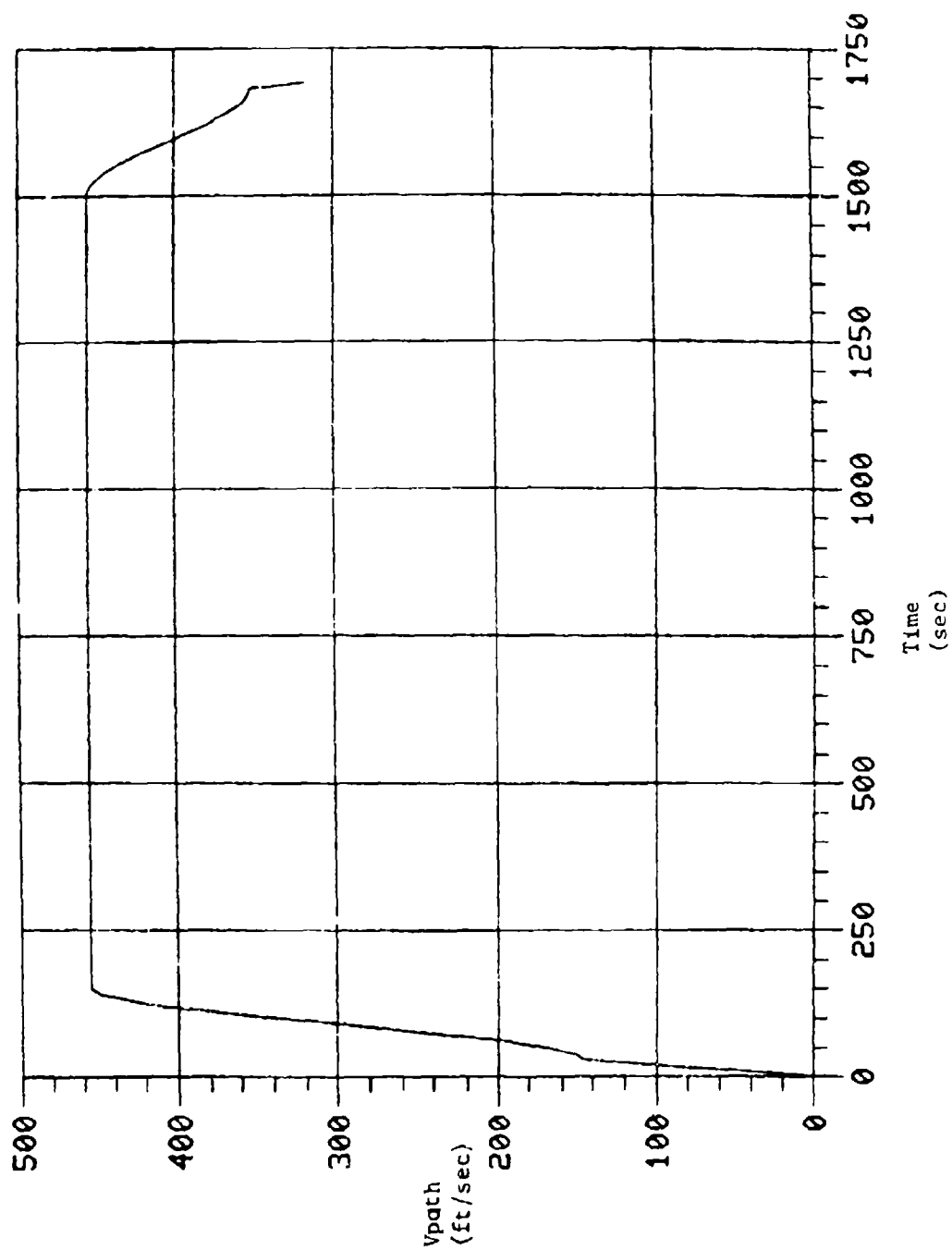


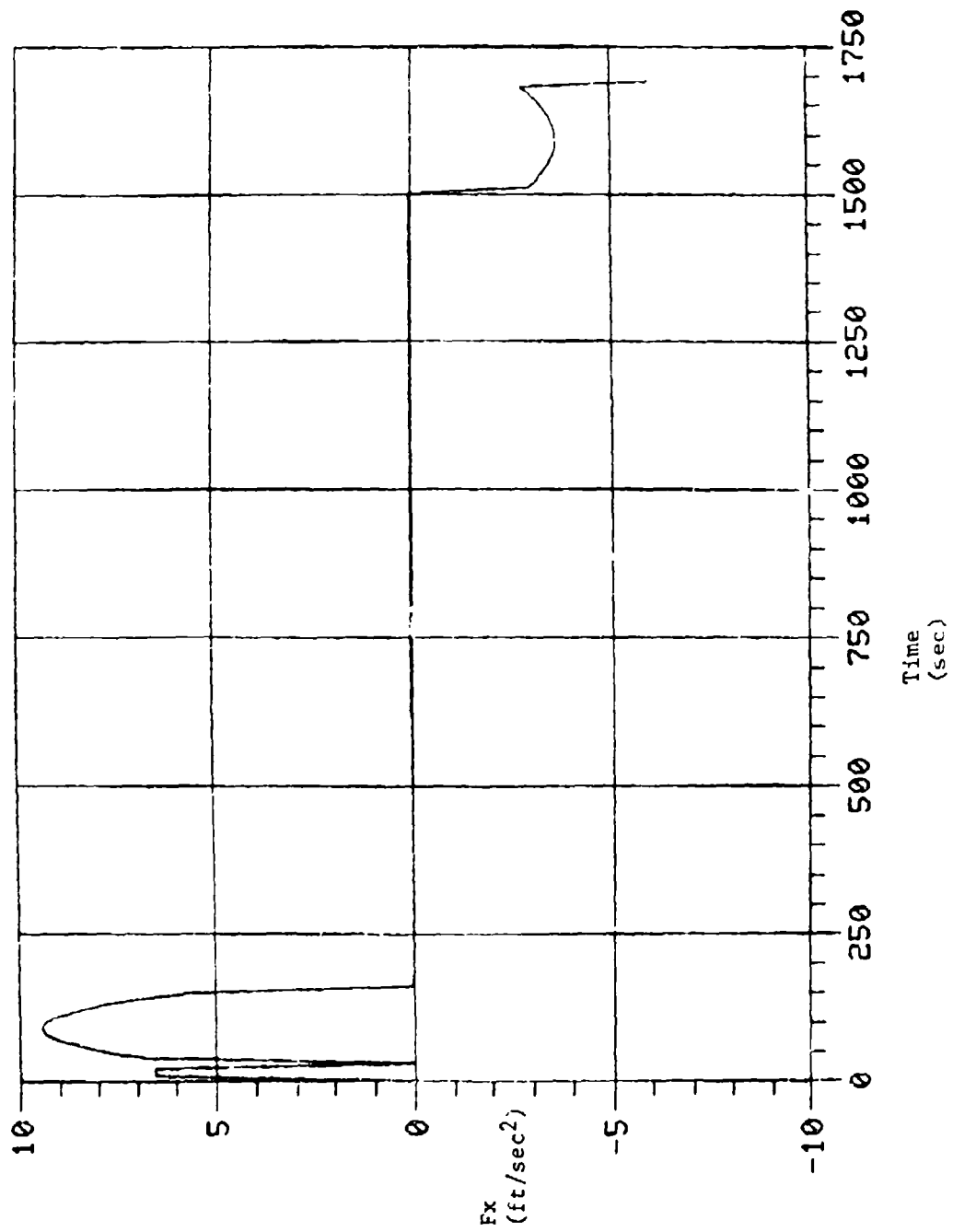


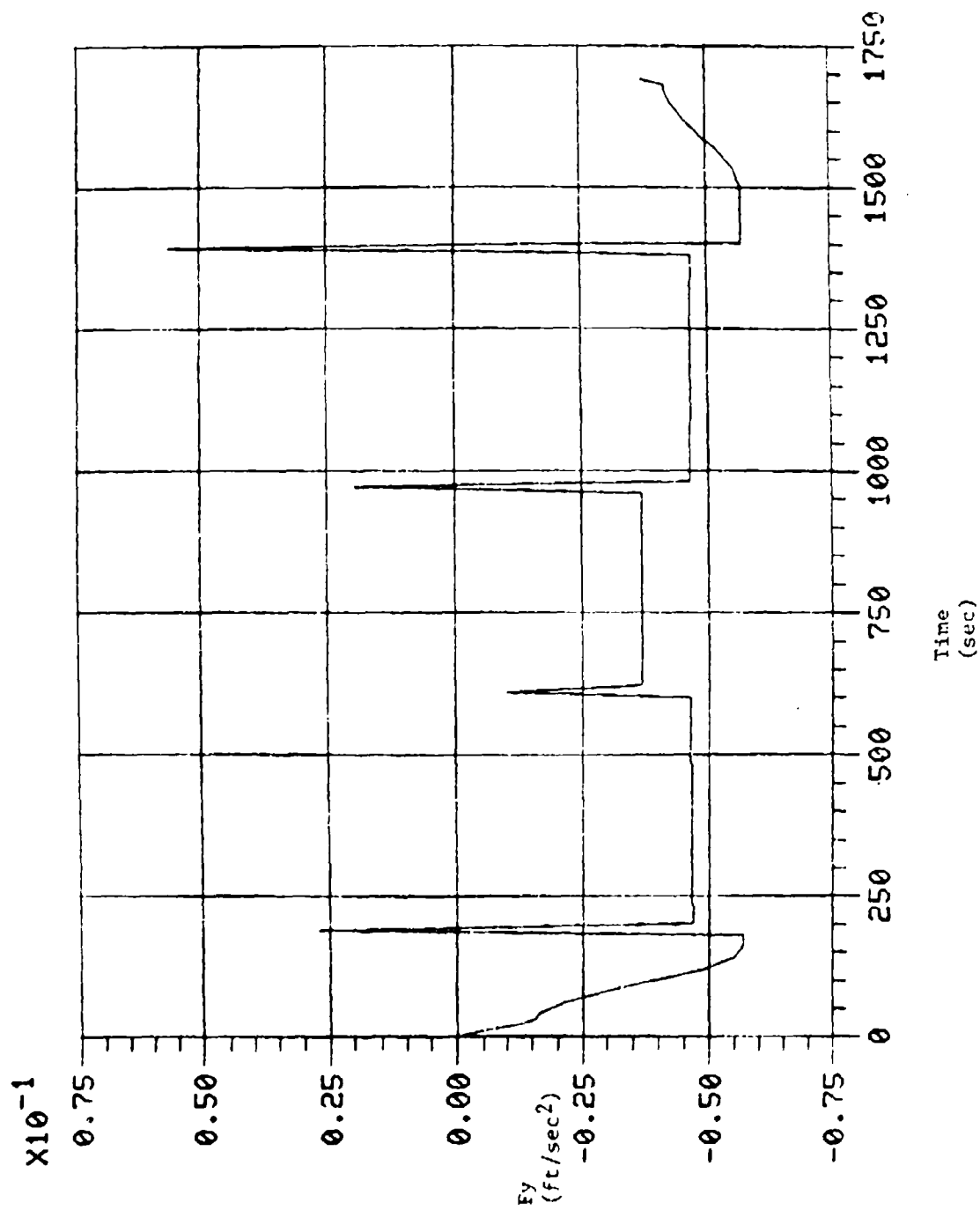


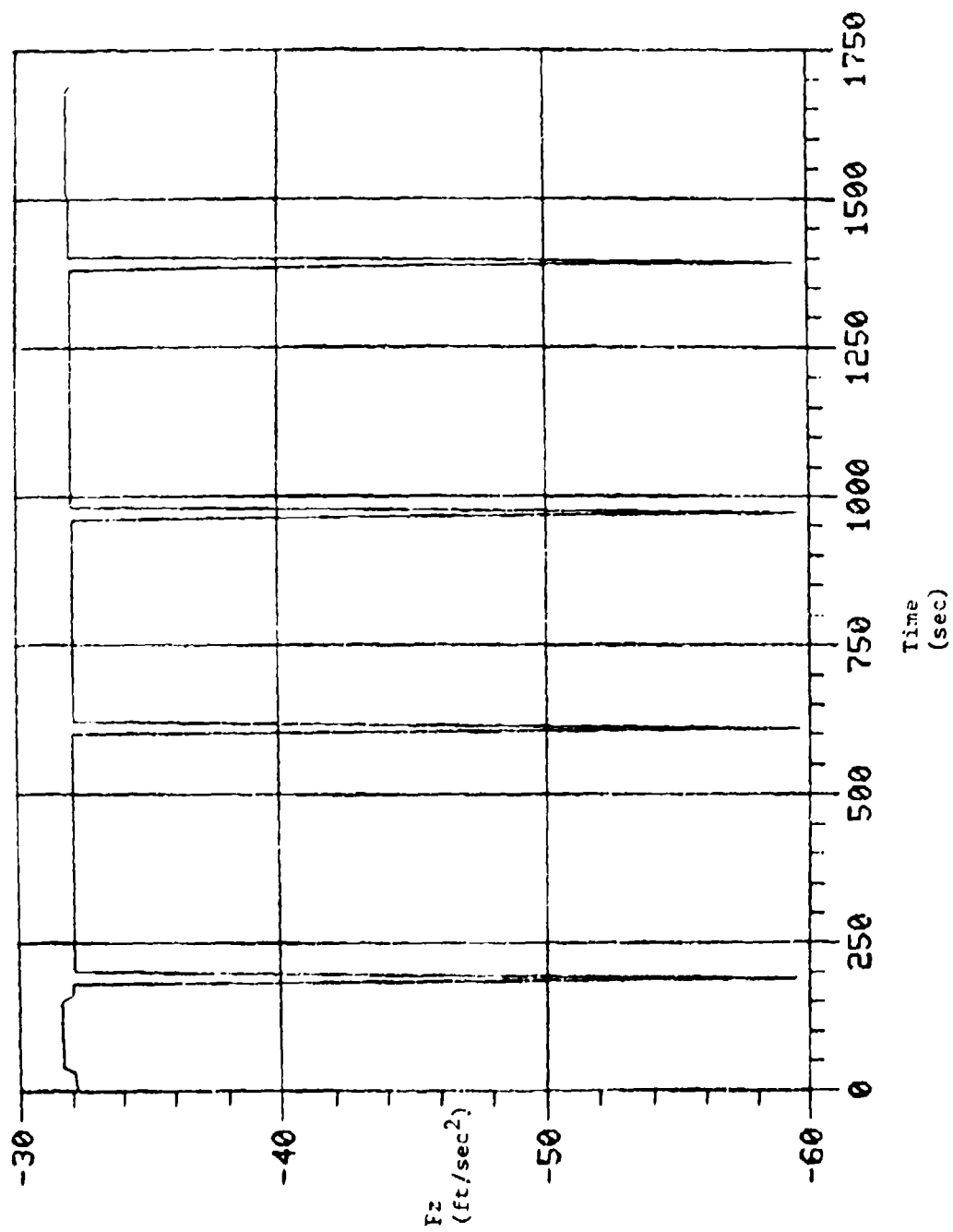


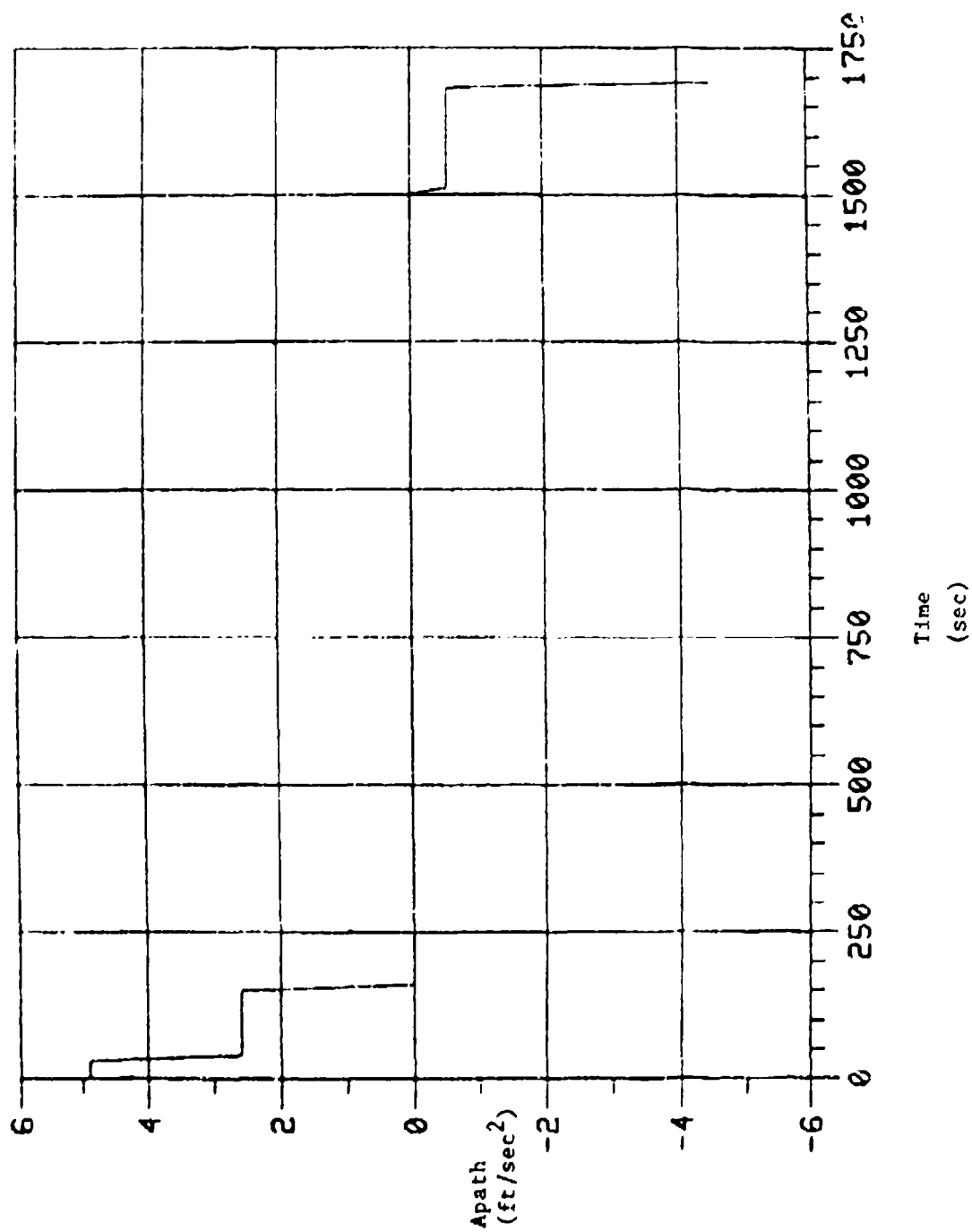












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13. ABSTRACT <p>PROFGEN, an aircraft flight profile generation program obtained from the United States Air Force Avionics Laboratory, has been modified for use in the simulation of a strapdown inertial navigation system being developed at DREO. The program allows the user to specify initial flight parameters to control the dynamics of a "point mass" aircraft in three dimensions. Outputs of PROFGEN are used to drive models of inertial sensors and develop navigation algorithms. An example flight profile employed in the simulation is described.</p>		

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Flight Simulation**

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